We note that the run-off at each month is made up of a residual plus a variable (*a*), which may be plus or minus in value, and the only thing we know about these variables is that their sum for the year is zero.

The Clough cycle probably does follow a similar cycle in the sun-spot numbers, but the correlation coefficient between the rate of change of sun-spot numbers and this variable cycle in run-off is only between plus 0.50 and plus 0.60—not good enough to work with.

It is the hope of the writer that these articles of Streiff will prove a stimulus to the profession, who owe it to themselves to at least investigate what might be to their benefit. Possibly within 10 years' time we will treat with simplicity what seems to us now a hard nut to crack.

FURTHER STUDIES ON THE ELECTRICAL CHARGES OF THUNDERSTORMS (A REPORT OF PROGRESS)

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Increased interest has been shown in the phenomena connected with lightning discharges during the last three years, due to the controversy between Simpson and C. T. R. Wilson in England and to the tremendous property losses caused by lightning in the United States. It should be remarked also that in the background behind any investigation of this kind is its relation to the earth's negative charge.

Simpson, in 1909, proposed what is known as the "breaking-drop theory" of the origin of electricity in thunderstorms which depends on rapidly ascending currents of air in a thunderhead and the observed fact that when a drop of water is broken up in the air the drop becomes charged positively and the air negatively. Raindrops from the active portion of such a cloud should carry positive charges and those from its more remote portions negative ones.

C. T. R. Wilson, by the use of an insulated ball and a capillary electrometer, succeeded in measuring the changes in the earth's field due to lightning and gave a ratio of 1 to 1:56 for positive to negative discharges. The more recent investigations by Schonland and Craib in South Africa (**1**), (**4**), (**5**), with apparatus essentially similar to Wilson's, give results in good agreement, both of them holding to the opinion that the lower pole of a thundercloud carries a negative charge.

In May, 1926, Simpson published a paper in which he maintained that a lightning flash originates only in the region of the maximum positive electric field and that any branching of the discharge will be in the direction of the seat of negative charges. He used as evidence on this point a large number of photographs of lightning flashes, of which 328 indicated that they were from positive clouds and 89 from negative. In April, 1927 (**2**), and more recently in November, 1929 (**3**), he gave a revised and amplified version of his theory of thunderclouds, in which he shows that the space charge of cloud should be positive in the active vortex, but that by far the larger portion of it should be negative. Lightning discharges are divided by him into three groups—(*a*) upward discharges from the head of the ascending air currents; these are thin, usually hidden by the cloud, and, if seen, would be branched upward. (*b*) Downward discharges from the same region, also thin, and branched downward. (*c*) Heavy flashes from the ground upward to the more quiescent part of the cloud. Where branching can be seen these are branched upward.

Our present series of observations at Nebraska Wesleyan began more than five years ago. Two papers have been read before this society (**6**), (**7**), and one before the American Physical Society (**8**), all in the nature of progress reports, for the problems involved are many and difficult of solution. The apparatus used consists of an insulated metal deck 9 meters above the earth, on the roof of the gymnasium which is adjacent to the physics laboratory. The deck is about 3 by 4 meters in size and has a capacity of 0.0014 microfarad. Adjacent to the deck is an insulated wire rectangle of the same dimensions as the deck and having a capacity of 0.0007 microfarad. Wires connect these conductors to earth through a sensitive galvanometer. A right-angle prism and rotating drum are used for making the records, the pencil carried by the parallel rods being kept over the spot of light by the observer. The capacity of the system and the ballistic constant of the galvanometer having been determined, the change in potential of the deck due to a given discharge may be computed. Values of changes in the potential gradient thus obtained have been consistently lower than those of other observers, due to tall trees and other surrounding objects.

In order to be able to identify a given discharge with the corresponding galvanometer deflection, a pair of telephone wires was run to the top floor of an adjoining 4-story building which presents a good view toward the western horizon. At the instant of a flash, word is sent to the observer in the laboratory, who records the data given on the drum. Differentiation is made between flashes from cloud to cloud and from cloud to earth. Notations are entered in a notebook of each lightning discharge regarding distance to cloud, size of flash, part of cloud from which flash came, etc. Likewise, when photographs have been taken, notes taken at the instant are used, together with the drum record and synchronized watches, to identify the picture.

During the season of 1928 observations were made on a total of 19 storms, 11 of which were in daytime and 8 at night. A total of 1,014 galvanometer deflections resulting from lightning discharges were recorded, 639 of which indicated a decrease of negative potential above the apparatus and 375 an increase of negative or a decrease of positive. Classifying as "distant" discharges beyond 8 kilometers and as "intermediate" those from 5 to 3 kilometers, the totals are 177 negative to 122 positive for distant discharges, 171 to 67 for the intermediates, and 298 to 196 for the "near" ones. It has here been assumed that our clouds hang lower than those observed by Schonland in South Africa, hence the reversal distance should be less than the 6.8 kilometers which he found. The fact that the ratio is larger for the intermediates than for the near ones would indicate either that this assumption is not well founded or that Wilson's theory does not account for all the facts. It should also be noted that the observations made prior to 1928 totaled 639 negative to 375 positive, a ratio practically identical with the more recent one, although no special efforts to check on distances were made in the earlier readings. Wilson's totals in his earlier paper gave a ratio of 1 : 1.56, positive to negative, while my present aggregates of 1,096 and 1,979, including the 1929 season, give a ratio of 1 : 1.80. In view of the radical difference in method used and the climatic differences between London and Lincoln, this is very good agreement, and would seem to justify a statement that this work supports Wilson's contention that the upper pole of the cloud is positive. However, the exceptions to the general average are so marked that they must be given careful consideration. For example, storm No. 19 on September 19, 1928, did not get nearer than about 5 miles at any time during the first hour that it was under observation and must be classed as a "distant" storm. Yet the record gives 128 discharges showing the lower pole negative to 33 positive. In the interval from 9:34 to 9:58 p. m. of that storm the ratio was 23 to 0 for the lower negative polarity. These conclusions are both on the basis of a bipolar cloud beyond the reversal distance. On Schonland's theory of reversals the ratio should have been reversed or the upper pole of the cloud must have been negative. Storm No. 5 on June 23, 1928, shows a ratio of 18 to 2 during the period from 12:46 to 1:12 a. m. for lower pole *positive*, the storm being directly overhead. This agrees nicely with Simpson's theory if we *knew* that the vortex was passing over at that time, *but* the ratios became even larger in the same direction as the storm passed on, which can not well be reconciled with the Simpson picture.

My galvanometer usually shows a continuous shift to right while rain is pouring down, and ballistic throws following lightning flashes are to left at the same time. This fact can be explained by recalling that the metal deck would collect the charges on the falling drops, deflection to right corresponding to negatively charged rain and left throws resulting from positive charges going to earth. The storm of June 23, referred to above, gave a shift to the left, as should be the case according to either theory, Simpson's or Wilson's. That the galvanometer shift is really due to the falling rain is proved by switching from the metallic deck to a wire rectangle of the same area but about one-half the electrostatic capacity. The rectangle reduces the shift almost to zero while still giving large deflections due to discharges.

The general trend of the evidence obtained is in favor of the Simpson theory for the cyclonic type of storm, but to account for some of the records we must assume that the positively charged vortex is much larger in some storms than in others; also that some storms move much more slowly than the rates usually given, 30 to 50 kilometers per hour, and may remain almost stationary for an hour or so until most of the energy they contain is dissipated.

It is obvious that if Simpson's picture of the distribution of charges in the thundercloud is correct there should be a brief period when the storm is approaching close by, and when its front is directly overhead, when instruments such as have been used by any of the observers to date should indicate a preponderance of positive charge overhead. This charge should be reduced by each lightning flash, only to be built up again by the action of the air currents in the storm. This would apply also to Norinder's method (**9**) of triangulation, as his stations were so close to each other as to be well within Schonland's reversal distance. Following this positive portion would come a much larger section of cloud in which the negative charges would predominate. Since change-of-potential readings have been taken for the whole cloud, and without regard to whether the storm passed directly over the observer or to one side, the large ratio of 1:80 to 1:00 for the lower pole of cloud negative is, in fact, in agreement with Simpson's theory. To maintain even so large a proportion of charges from a positive cloud as we have it is necessary that this part of the storm be much more active than the other.

D. Nukiyama and H. Noto (**10**) have recently suggested that the thunderstorms found inland in Japan are of the Simpson type while those along the seacoast conform to the Wilson bipolar scheme with lower pole negative. These observers are using a galvanometer system similar to mine, with the added advantage of a photographic recording device, but state that their total number of observations is too small to warrant any general conclusions. In a later paper Noto (**11**) reports both negative and positive fields, and leans to the dipole pattern. In this instance, also, the conclusion is drawn from meager data and could as well be accounted for by Simpson's type of cloud as shown by some of the type cases studied theoretically by Simon (**12**).

Simpson has suggested the desirability of obtaining pictures of lightning flashes with the corresponding data regarding field changes. He points out the necessity of knowing definitely what part of the storm is overhead the instant when a given field-change observation is recorded. We have met the first of these requirements by taking a number of pictures concerning which the field-change data is also on record and find that in the active front of the cloud most of the discharges to ground are forked downward, as required by Simpson, and that in the secondary part, the other type with branches upward, predominates. Our pictures disagree with Simpson's requirements that flashes from the positive part of a cloud are thin, as these are the brightest and hottest discharges we have.

To learn the rate of motion of the storm, whether its center has passed over the observer, the rapidity and magnitude of the pressure changes connected with different parts of the storm, etc., four Tycos microbarographs have been secured. One is in the laboratory at Nebraska Wesleyan, one about 3½ miles south in College View, and the third 5 miles north on the hills north of Salt Creek. A fourth is in the Lincoln Weather Bureau office. These instruments were made available through grants from the Hodgkins fund of the Smithsonian Institution, and from the University of Nebraska, and the loan of one from the United States Weather Bureau at Washington. They were put into service on July 22, 1929. The month of August was dry and lacking in well-developed storms at Lincoln, but records obtained give promise that the instruments are capable of doing the work required of them and that the mooted questions to the present controversy may be put to a crucial test during the coming thunderstorm season.

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